TITLE OF THE INVENTION

APPARATUS FOR ACCELERATING CONDENSATION WITH THE AID OF STRUCTURED SURFACES

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The invention relates to an apparatus and method for condensing gases. An important parameter for many industrial processes is the condensation behavior of a vapor/gas. For the purposes of the present invention, condensation is the phase change of an element or of a compound from a gaseous phase into a liquid phase.

DISCUSSION OF THE BACKGROUND

Taking the example of the water/air system, i.e. humidity, a certain percentage of water vapor is present in the air of the outdoor atmosphere. This water vapor is termed humidity. The ratio of the mass of water vapor present in a volume of air to that volume of air is termed the absolute humidity. However, a more important value is that known as relative humidity. Relative humidity is defined as the mass of water vapor present in a volume of air divided by the mass of water vapor when that volume of air is saturated, and can be

$$\varphi = \frac{P_D}{P_S} = \frac{f}{f_{\max}}$$

described by the following formula:

where φ = relative humidity; P_D = water vapor partial pressure; P_s = saturation vapor pressure; f = absolute moisture level; f_{max} = maximum moisture level.

Relative humidity of 100% therefore means that the water vapor partial pressure is the same as the saturation vapor pressure of water at a given temperature and pressure. It is known from thermodynamics that for two phases to exist alongside one another in equilibrium their chemical potentials have to be identical. Liquid phase and vapor phase can therefore only exist alongside one another at a certain pressure, which is temperature-dependent.

Condensation processes are used in a wide variety of industrial processes, e.g. distillation, reactive distillation, cooling water circuits in power plant turbines, and work-up of aqueous or organic solutions by drawing off the solvent. These processes therefore have a major part to play in industry.

The energy balance is an important economic criterion here, implying that the less energy needed to condense a liquid, the more cost-effective the condensation process. This process may be described as follows, taking the example of condensation of water vapor from air:

A surface (condenser) is cooled with respect to the surrounding gas phase. In the immediate vicinity of the surface there is cooling of the gas and of the water vapor. If the pressure is held constant here, the prevailing water vapor partial pressure can exceed the saturation vapor pressure associated with the lower temperature. In that case condensation occurs, leading to deposition of water on the surface. The droplet present on the surface then gives up heat to the surface and thus cools. In many types of condensation apparatus, this transfer of heat has to be compensated, therefore requiring constant recooling of the condensation surface. The cooling of these surfaces is a very energy-intensive process. The greater the amount of condensate on the surface and the longer its residence time, the more energy the condensate gives up to the surface. It is therefore desirable that the water droplet is conducted away from the surface as rapidly as possible and that its temperature is as high as possible at that juncture.

SUMMARY OF THE INVENTION

It is an object of the present invention, therefore, to improve the economics of the condensation process, i.e. the process extending from condensation of a vapor to collecting the resultant liquid.

DETAILED DESCRIPTION OF THE INVENTION

Surprisingly, it has been found that increased condensation efficiency is possible with the aid of a structured surface.

The present invention provides an apparatus and method for condensing a gas on a surface, where the surface for condensing the gas (condensation surface) has elevations of

average height of from 50 nm to 1 mm, and with an average separation of from 50 nm to 1 mm.

The arrangement of the elevations may be regular (ordered) or stochastic (randomly distributed). The elevations may moreover have an average height of from 500 nm to 50 μm.

The surface energy may be from 5 to 20 mN/m, preferably from 10-20 mN/m. Higher surface energies, such as from 20-40 mN/m, are also possible but are not generally necessary, e.g. for condensing water.

Structured surfaces are known and termed lotus surfaces, and have been described, e.g. in DE 198 03 787 and WO 96/04123, both incorporated herein by reference, where the self-cleaning action of the structured surfaces is described.

Those surfaces of the apparatus of the invention at which the vapor condenses have a very small run-off angle for liquids, in this case for the condensate. Once a condensed droplet has begun to move, it can run off the surface without assistance and can collect other droplets, and this applies even to very small droplets. A droplet size below 0.5 μl is sufficient for this purpose. The droplets therefore have relatively low adhesion to the surfaces and thus run off from the surface relatively rapidly. This phenomenon affords many thermodynamic/technical advantages. The shorter residence time of the condensate on the surface reduces the amount of heat which can be given up by the liquid to the surface, since this process proceeds in proportion to temperature difference and time. The results of the more rapid transport of the condensate away from the surface are firstly that less energy is transferred and secondly that what are known as condensation nuclei are made available again more rapidly.

The sites at which the liquid phase is produced are termed condensation nuclei. Condensation within the vapor has to begin with formation of small droplets. The smaller the droplet, the greater its vapor pressure, and therefore at a given level of oversaturation the droplets that can grow are only those whose radius exceeds a certain value. All droplets with a smaller radius tend to re-evaporate. Condensation of the oversaturated vapor can take place only after a nucleus has been produced as a result of a fluctuation phenomenon associated with a fall in entropy. The frequency of this nucleation is a decisive factor in determining whether a phase change from gaseous to liquid is likely to occur at a given level of oversaturation. The frequency is found to be very sensitive to the level of oversaturation of the vapor/gas. Within a relatively narrow range of oversaturation levels, the scale will extend

from almost no condensation events to very frequent condensation events. Whether oversaturation of the vapor is present or not depends to a major extent on the microscopic environmental parameters applicable to the vapor.

The condensation surface of the present invention therefore preferably has one or more of the following features:

· an angle of inclination of at least 3°, in particular at least 10°, preferably at least 30°, particularly preferably at least 45°,

· a surface energy of from 5-20 mN/m, determined on a surface without elevations (by the method of Owens et al., J. Appl. Polym. Sci. 13, 1741, 1969, incorporated herein by reference),

· a material: polytetrafluoroethylene, polyvinylidene fluoride, or polymers made from perfluoroalkoxy compounds, and/or metals, as sole constituent, main constituent, or coating,

· a coating made from fluoroalkanes, from alkyl- fluorosilanes, or from fluorinated vinyl compounds.

The apparatus of the invention may be used in cooling systems, distillation systems, reactors, reflux condensers, or power plant condensers, or else in air conditioning systems, dehumidifiers, or cold traps. The apparatus may contain a means for removing condensate formed on the condensation surface. Such means may rely on gravity for drawing the condensate liquid to a reservoir or outlet from the apparatus. A preferred means of removing condensate utilizes gravity to allow the condensate to move under the influence of its own weight down the condensation surface to a removal or containment reservoir or outlet from the apparatus. It is preferred to orient the condensation surface at an angle to improve the condensate's ability to move under the influence of gravity.

The method of the invention may be used to improve the energy efficiency of any process that involves condensing a condensable gas. The method may be conducted by bringing a condensable gas into contact with the condensation surface. The condensation surface is preferably cooled. The pressure of the condensation gas is preferably substantially constant and may be adjusted so as to change the rate of condensation of the gas on the condensation surface. The rate of condensation may be further regulated by adjusting the cooling of the condensation surface.

Particular applications of the invention include cooling, distillation, or condensation systems for any of the elements and compounds which can change their phase from gaseous to liquid, in particular for water, ethanol, methanol, MTBE, hydrocarbons, fuels, combustion gases, or liquefied gases, such as N_2 or air.

In the invention method, a gas containing a condensable vapor is brought into contact with the invention condensation surface, preferably with cooling of the condensation surface and collection of the resultant condensate.

German Application Number 100 65 797.4, filed on December 20, 2000, is incorporated herein by reference in its entirety.

BRIEF DESCRIPTION OF THE DRAWING

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein the condensation apparatus of the Examples is shown.

EXAMPLE 1:

A negative shape was produced by UV lithography of a photosensitive plastic and subsequent electroforming with nickel according to EP 0 933 388, incorporated herein by reference. This shape was used to cast a polycarbonate film having a microstructure with protuberances of about 2 μm wide (measured at half height) and about 4 μm height with a spacing of 4 μm. The structure of the shape has the same dimensions with opposite sign.

The polycarbonate film structured in this manner was then rendered hydrophobic with Dynasilan F 8262 (Degussa AG). An unstructured polycarbonate film was also rendered hydrophobic with Dynasilan F 8262 (Degussa AG). A polycarbonate film rendered hydrophobic in the same manner but unstructured had a contact angle with water of 109.8° and a surface energy of less than 20 mN/m (determined according to Owens et al.) and the structured film a contact angle of 150°.

A second negative shape was produced in the same manner as described above. With the second shape a polycarbonate film having protuberances of about 0,5 μm wide (measured at half height) and about 0,5 μm height with a spacing of 0,5 μm, was produced.

The films having different structured surfaces as well as a hydrophobic and unstructured polycarbonate film were fixed on the outside of metal tubes. Those tubes were one after another installed into a second, larger tube. The first tube was cooled by streaming cooling water (10 °C) through the inside of the tube. The larger tube was filled with steam of water having a pressure of 10^5 N/m^2. A schematic picture of this arrangement is given in the drawing.

The inner tubes with the different films fixed on the outside were exchanged after a given period of time. The water condensed on the different sheets or films in the same period of time was collected and weighted. The mass of the water collected on structured surfaces was at least 50% higher than the mass of water collected on the tubes having hydrophobic but non structured surfaces. There was no significant difference in the mass of water collected on structured surfaces having protuberances with a wide of 2 μm and those having protuberances with a wide of 0.5 μm.

EXAMPLE 2:

The same negative shape as described in the Example above can be used to form a structured nickel sheet by galvanic forming. This sheet once again can have a microstructure with protuberances of about 2 μm wide (measured at half height) and about 4 μm height with a spacing of 4 μm.

A nickel sheet with this structure can be rendered hydrophobic with Dynasilan F 8262 (Degussa AG). An unstructured nickel sheet can also be rendered hydrophobic with Dynasilan F 8262 (Degussa AG).

A second negative shape can be produced in the same manner as described above. With the second shape a nickel sheet can be produced having protuberances of about 0,5 μm wide (measured at half height) and about 0,5 μm height with a spacing of 0,5 μm.

The sheets with different structured surfaces as well as a hydrophobic and unstructured nickel sheet can be fixed on the outside of metal tubes. Those tubes can be installed one after another into a second, larger tube. The first tube can be cooled by streaming cooling water (10°C) through the inside of the tube. The larger tube can be filled with steam of water having a pressure of 10^5 N/m^2.

The inner tubes with the different sheets on the outside can be exchanged after a given period of time. The water that can condense on the different sheets in the same period of time can be collected and weighted. On structured surfaces, the mass of the water that could be collected is at least 50% higher than the mass of water for the tubes with hydrophobic but non structured surfaces. The mass of water that could collect at the tube can be much higher when using tubes having metal sheets fixed on it instead of polycarbonate films. There is no significant difference expected in the mass of water collected on structured surfaces with protuberances with a wide of 2 μm and those with protuberances with a wide of 0.5 μm.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.